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Optimal viewing position effects in the processing of isolated Chinese words

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ABSTRACT

Previous studies have found that words are identified most quickly when the eyes fixate near the word center (the Optimal Viewing Position, OVP) in alphabetic languages. Two experiments were performed to determine the presence of OVP effects during the processing of isolated Chinese words. Participants' eye movements were recorded while they performed a lexical decision task. The results suggest that Chinese readers exhibit OVP effects and that the OVP tends to be the first character for 2-character words. For 3- and 4-character words, the OVP effects appear as a U-shaped curve with a minimum towards the second character. As fixations deviate from the OVP, word processing times increase at a rate of 30–70 ms per character, and fixation duration is strongly influenced by the initial viewing position. Moreover, the present study did not observe an I-OVP effect for first fixation durations nor a fixation-duration trade-off in two-fixation cases in the case of isolated Chinese words processing.

1. Introduction

The goal of the present study was to investigate during the reading of isolated Chinese words, the optimal viewing position (OVP) effect, a very well know phenomenon in the reading of alphabetic languages. A word tends to be most efficiently recognized when the eyes initially fixate on the OVP, which tends to be near the center of short words and slightly to the left of the center of long words (O'Regan & Lévy-Schoen, 1987; O'Regan et al., 1984; Van der Haegen, Drieghe, & Brysbaert, 2010). As the initial viewing position deviates from the OVP, processing time increases at a rate of 20–30 ms per letter (O'Regan et al., 1984). The OVP pattern found with isolated words could provide key insights into understanding visual word recognition processes (Brysbaert, Vitu, & Schroyens, 1996; Clark & O'Regan, 1999; O'Regan & Jacobs, 1992). Brysbaert and Nazir (2005) proposed that it may be due to an interplay of many factors including visual acuity, information structure of the word stimuli, perceptual learning based on reading habits and hemisphere lateralization.

Besides affecting the efficiency of word recognition, the initial viewing position also influences eye movement behavior in alphabetic languages (Hyönä & Bertram, 2011; Joseph et al., 2009; McConkie et al., 1988, 1989; McDonald, Carpenter, & Shillcock, 2005; Nuthmann, Engbert, & Kliegl, 2007; Vitu et al., 2001; Vitu, O'Regan, & Mittau, 1990). In natural sentence reading, eye movement studies have documented that readers initially tend to fixate on a point between the beginning and the center of a word, which has been referred to as the preferred viewing location (PVL) effect (Rayner, 1979). McConkie et al. (1988) have proposed that the target of the initial fixation within a word is near the center of the word and corresponds to the OVP, but that the fixation location shifts from the OVP to the PVL due to both systematic and random oculomotor errors. Consequently, the OVP may represent the optimal position for word perception, while the PVL represents the actual fixation location in sentence reading.

The initial viewing position influences several indexes of eye movement behavior such as refixation probability and fixation times. During the processing of isolated words and words in sentences, the frequency of a refixation within a word is lowest when the initial fixation is near the center of the word. As the initial fixation deviates from the word center, readers are more likely to refixate the word. This Refixation-OVP effect has been replicated in many studies (Hyönä & Bertram, 2011; Joseph et al., 2009; McConkie et al., 1989; McDonald & Shillcock, 2005; Nuthmann, Engbert, & Kliegl, 2005; Rayner, Sereno, & Raney, 1996; Vitu, Lancelin, & d'Unienville, 2007; Vitu, O'Regan, & Mittau, 1990; Vitu et al., 2001). Correspondingly, the Gaze-Duration OVP effect shows that the total fixation time on a word during the first time reading is shorter for initial fixations that occur near the center of the word than towards the word's ends (O'Regan, 1990; O'Regan & Jacobs, 1992; O'Regan et al., 1984). However, the Gaze-Duration OVP effect is weaker during sentence reading than during the reading of isolated words (Nuthmann, Engbert, & Kliegl, 2005; Rayner, Sereno, & Raney, 1996; Vitu, O'Regan, & Mittau, 1990). Furthermore, Vitu et al. (2001) reported an inverted optimal viewing position (I-OVP) effect, demonstrating that the duration of single

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fixations, as well as the duration of the first of two fixations, is longer when fixations are located toward the center of words than when they are located near the words' ends (McDonald, Carpenter, & Shillcock, 2005; Vitu, Lancelin, & d'Unienville, 2007; Vitu et al., 2001). Meanwhile, words that are fixated twice exhibit a fixation-duration trade-off effect (Hyönä & Bertram, 2011; McDonald, Carpenter, & Shillcock, 2005; O'Regan & Lévy-Schoen, 1987; Vitu, O'Regan, & Mittau, 1990; Vitu et al., 2001). Two consecutive fixations tend to consist of either a brief initial fixation on a nonoptimal word region followed by a longer fixation within the word or of a longer initial fixation near the OVP followed by a shorter fixation within the word.

In the past 20 years, several theories and models of eye movement control in reading have been proposed which provide alternative explanations for viewing position effects. Some models have assumed that eye movement behavior is largely influenced by oculomotor constraints, whereas other models have assumed that eye movements are driven by ongoing lexical processing (for a review see Rayner, 2009). O'Regan and Lévy-Schoen (1987) proposed the strategy-tactics theory, which suggests an oculomotor interpretation for the Refixation-OVP effect. The basic assumption is that within-word eye behavior is determined by readers' predetermined oculomotor scanning routines and by their perceptual experiences that words are most easily processed when the eyes fixate on their center. When the eyes fixate on a word, a detection mechanism might first estimate the current fixation location on the word, and then decide where to send the eyes next. If the eyes land near the word center, a single fixation is planned since the word is likely to be recognized with a single fixation. If the eyes fixate near one of the word's ends, a refixation is automatically programmed, thus producing the Refixation-OVP effect. This theory is supported by research findings that the Refixation-OVP effect also occurs during the processing of meaningless letter strings, which does not involve language processing (Nazir, 1991; Nuthmann & Engbert, 2009; Vitu et al., 1995).

An alternative account of the Refixation-OVP effect comes from cognitive-control models, such as the E–Z Reader (Pollatsek, Reichle, & Rayner, 2006; Reichle et al., 1998; Reichle, Pollatsek, & Rayner, 2012,; Reichle, Rayner, & Pollatsek, 1999, 2003), SWIFT (Engbert, Longtin, & Kliegl, 2002; Engbert et al., 2005; Richter, Engbert, & Kliegl, 2006), Glenmore (Reilly & Radach, 2006) and others. Note that Glenmore proposes a mixed account of the Refixation-OVP effect, assuming that it results from early visuo-motor strategies and later, ongoing word identification processing. These models assume that the degree of difficulty of ongoing word processing affects both refixation probability and fixation duration: the more difficult a word is, the higher the refixation probability and the longer the fixation duration is. When the eyes fixate on the center of the word, where visual word recognition is most efficient, a within-word refixating saccade is less likely to occur than when the eyes fixate towards one of the word's ends. If the eyes land far from the word center, it may be difficult to recognize the word, and the eyes have to fixate on the word again, producing a Refixation-OVP effect. Recently, McDonald, Carpenter, and Shillcock (2005) presented the SERIF model, which offers new insight into how anatomical, oculomotor, and perceptual-visual factors combine to produce eye movement behavior in reading. However, the model did not include explanations for within-word refixations.

Several models and theories have attempted to account for the fixation-duration trade-off. The strategy-tactics theory assumed that the same amount of time is necessary for any given word to be identified (O'Regan & Lévy-Schoen, 1987; Vitu, O'Regan, & Mittau, 1990). Thus, the longer the time demanded by the detection mechanism, the less additional time is needed for word recognition. When a word receives two consecutive fixations, the first fixation duration is assumed to be longer toward the word center than toward its ends, whereas the second fixation duration is inversely related to the eyes' initial viewing position. Thus, the theory can account for the fixation-duration trade-off effect.

Recently, some interpretations have been proposed to explain the I-OVP effect. First, the mislocation hypothesis assumes that single fixations or the first of multiple fixations that fall on the word boundaries are not intentional, but are the result of the oculomotor system overshooting or undershooting the center of words (Engbert et al., 2005; Nuthmann & Engbert, 2009; Nuthmann, Engbert, & Kliegl, 2005, 2007). These mislocated fixations would subsequently trigger early saccade programs, thereby decreasing the fixation duration near the word boundaries and also increasing the likelihood of refixations due to the needs of ongoing processing. Second, an anatomical account was proposed in McDonald, Carpenter, and Shillcock's (2005) SERIF model to explain the I-OVP effect. This assumes that the stimuli present in the right side of the fovea are projected onto the left hemisphere, whereas stimuli in the left side of the fovea are projected onto the right hemisphere. Prolonged fixations at the word center result from prolonged competition when the information content is similar between the left and right hemispheres. In contrast, when the fixation lands on one of the word's ends, the competition will be soon over due to unbalanced competitors. Third, Vitu, Lancelin, and d'Unienville (2007) proposed the perceptual-economy hypothesis to explain the I-OVP effect (see also Vitu et al., 2001). The hypothesis assumes that fixation durations are prolonged at locations in words that are anticipated to provide greater information for word identification. When the eyes land on a word, their location relative to the word boundaries is first estimated, then based on this estimation and the reader's perceptual experience, the onset time of the next saccade is determined. Because most information for word recognition can be extracted from the word center, the hypothesis predicts the longest fixation will occur at the word center, regardless of whether it is followed by a second fixation or not. Thus, the hypothesis can account for both the fixation-duration trade-off and the I-OVP effect.

Although the OVP as well as fixation-duration trade-off effects have been examined in alphabetic languages, the results found may not generalize to Chinese. First, written Chinese differs from English because there are no physical cues (e.g., spaces) between written words, and Chinese readers must identify words based on lexical knowledge and contextual information (Hoosain, 1991; Li, Rayner, & Cave, 2009). Second, Chinese words are typically shorter than words in alphabetic languages. According to the Chinese Lexicon (2003), 2.8% of Chinese words are 1-character words, 63.9% are 2-character words, 17.5% are 3-character words, 14.2% are 4-character words, and less than 1.7% contain more than four characters. In contrast, word length in English is highly variable and ranges from 1 to more than 20 letters (Inhoff & Liu, 1998). Third, the characters forming words in Chinese are part of a set of more than 5000 Chinese characters. In contrast, English words are composed of letters drawn from a set of 26 letters. Fourth, individual Chinese characters differ in complexity due to variations in the number of strokes, the number of radicals, and the manner of construction. Thus, characters in Chinese have considerably greater information density than letters in English (Hoosain, 1991; Yan et al., 2006). In addition, Chinese and English readers exhibit different perceptual spans. In Chinese, the span extends from 1 character to the left of fixation to 2–3 characters to the right of fixation; in English, it extends from 3–4 letters to the left of the fixation to approximately 14–15 letters to the right of the fixation (Inhoff & Liu, 1998). Consequently, the eye movement control during reading might differ in Chinese as compared to alphabetic languages such as English. Thus, it is necessary to separately determine the extent to which the initial viewing position affects word recognition in Chinese.

Some studies have investigated PVL phenomenon in non-alphabetic languages such as Chinese and Japanese, and they show different patterns of results across tasks (Kajii, Nazir, & Osaka, 2001; Li, Liu, & Rayner, 2011; Sainio et al., 2007; Shu et al., 2011; Tsai & McConkie, 2003; White, Hirotani, & Liversedge, 2012; Yan et al., 2010; Yang & McConkie, 1999). In Japanese, Kajii, Nazir, and Osaka (2001) and Sainio et al. (2007) reported that the PVL peaked at the beginning of a word for Kanji–Hiragana text. Sainio et al. (2007) found that landing initially in the word beginning resulted in longer gaze duration and total fixation time relative to the middle or end zone of words. Recently, White, Hirotani, and Liversedge (2012) found that there was no PVL for two-character kanji words. In Chinese, Yan et al. (2010) and Shu et al. (2011) have found that saccades landed near the word center for single fixations, whereas saccades landed near the word beginning for the first of multiple fixations. However, Li, Liu, and Rayner (2011) have presented simulation results showing that even a simple model that assumes that saccades travel constant distances could generate the same types of initial fixation distributions as observed by Yan et al. (2010). Additionally, Li, Liu, and Rayner (2011) found that there is no evidence that Chinese readers target any specific position within a word during Chinese reading. Moreover, several other studies have not found the PVL phenomenon in Chinese reading (Tsai & McConkie, 2003; Yang & McConkie, 1999). Thus, unlike PVL in alphabetic languages, there is no direct evidence of a PVL in Chinese, perhaps due to the lack of spaces separating words in written Chinese.

In addition, several studies have reported Refixation-OVP and I-OVP effects in natural reading. Regarding refixation strategies, both Chinese and Japanese readers produce monotonically decreasing rather than quadratic trends functions. When the first fixation occurs at the word beginning, the probability of refixating on a word is highest (Kajii, Nazir, & Osaka, 2001; Li, Liu, & Rayner, 2011; Yan et al., 2010). Yan et al. (2010) found the I-OVP effect for single-fixation durations on 2-character words with four levels of half character zones in natural Chinese reading: an inverted U-shaped curve of single fixation duration as a function of initial landing position with a maximum towards the first half character zone of the second character. Note that the effect was numerically much smaller than in alphabetic languages, perhaps due to the greater information density and physically smaller words in Chinese than in alphabetic languages. Based on the features of Chinese words, an I-OVP effect may not necessarily be predicted in the present study.

At the same time, less is known regarding systematic OVP effects during word recognition in logographic writing systems such as Chinese. An OVP effect similar to that found in alphabetic languages might be found during the processing of isolated Chinese words because word boundaries of isolated words can be detected by participants. Indeed, according to both the strategy-tactics theory and the perceptual-economy account of the fixation-duration I-OVP effect, visuo-motor strategies based on the extraction of word boundaries underlie the effects of fixation location on eye behavior. If Chinese readers have developed perceptual-motor strategies, Refixation-OVP and I-OVP effects may be observed and this for word and non-word stimuli. However, because there are no inter-word spaces in Chinese reading, it is unclear whether Chinese readers have indeed developed perceptual-motor strategies which rely on the extraction of word boundary information, similar to readers of alphabetic languages.

The present study explores how initial viewing position affects the processing of isolated Chinese word using the same paradigm that was used to study the OVP effects in alphabetic languages (O'Regan & Jacobs, 1992; O'Regan et al., 1984). The initial viewing position in words was systematically manipulated by shifting words horizontally relative to an imposed initial viewing position, and variations in processing time and eye behavior were measured as a function of initial viewing position. In the two experiments, stimuli were either words or nonwords of variable lengths (2–4 characters), and participants were asked to perform a lexical decision task. In Experiment 1, the stimulus was presented for 80 ms, and only accuracy and lexical decision time were reported. In Experiment 2, the stimulus was presented for unlimited duration, and word recognition performance as well as eye movement measures were reported.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twelve native Chinese speakers (6 females) with normal or corrected-to-normal vision were recruited from universities in Beijing near the Institute of Psychology and were paid 35 Yuan (approximately five US dollars) to participate in the experiment. They ranged in age from 22 to 30 years old ($M = 22.9$, $SD = 2.5$). All participants were unaware of the purpose of the experiment.

2.1.2. Materials

The stimuli consisted of 540 words and 540 nonwords. The word stimuli were selected from the Chinese Lexicon (2003). The nonword stimuli were constructed by combining randomly selected characters. During pretesting, 3 native Chinese speakers agreed that all of the words in the word condition were valid words, that the nonword stimuli were not words, and that none of these consecutive characters in the nonword strings could combine to compose a word. For word stimuli, the mean word frequency was 13.7 ($SD = 45.4$) occurrences per million, the mean character frequency was 937.6 ($SD = 1383.5$) occurrences per million, and the mean number of strokes per character was 8.0 ($SD = 2.5$). For nonword stimuli, the mean character frequency was 932.9 ($SD = 1334.2$) occurrences per million and the mean number of strokes per character was 8.1 ($SD = 2.5$).

Both word and nonword stimuli were composed of 2, 3, or 4 characters, and each character within a stimulus served as an initial viewing position during the experiment. There were 60 stimuli in each of the position conditions for the different word and nonword lengths. Thus, there were 120, 180, and 240 stimuli for 2-, 3-, and 4-character words, respectively. In total, there were 1080 experimental trials that were presented in random order to each participant after 36 practice trials. Although each participant viewed the entire set of word and nonword stimuli, the character that served as the initial viewing position for a particular stimulus differed across participants. For each word or nonword, equal numbers of participants viewed the stimuli at any of possible initial viewing positions. For example, for a 3-character word, four participants viewed it at the first character, four participants viewed it at the second character, and another four participants viewed it at the third character. Because the same word was presented to different participants with different initial viewing positions, the effect of the initial viewing position for words of a particular length could be determined. However, the design did not allow the results for words that differed in length to be compared because words differing in length also differed in their frequency, complexity, and character features. Although investigation of these factors might be worthwhile, it was beyond the scope of the present research.

2.1.3. Apparatus

Eye movements were recorded with an EyeLink 1000 eye tracker (SR Research, Osgoode, Canada). Although viewing was binocular, only the right eye was monitored. The materials were displayed on a 21-in. CRT monitor with a resolution of 1024 × 768 pixels and a refresh rate of 150 Hz that was connected to a Dell PC. All materials were presented in white (RGB: 255, 255, 255) on a light gray background (RGB: 128, 128, 128). The contrast was low to prevent participants from experiencing eye fatigue. Each stimulus was displayed on a single line in Song 24-point font, and the size of each Chinese character was 32 × 32 pixels. Participants were seated at a viewing distance of 58 cm from the computer monitor; at this viewing distance, each character subtended a visual angle of approximately 1.2°.

2.1.4. Procedure

Participants were tested individually. Their eye movements were recorded while they performed a lexical decision task for each series of character strings by pressing a button. At the beginning of the experimental session, participants performed a calibration procedure by looking at a sequence of three fixation points that were horizontally displayed randomly at the middle of the computer screen; the calibration error was less than 0.5° of visual angle. At the beginning of each trial, a fixation cross (subtending approximately 0.6° × 0.6°) was displayed at the center of the screen. After participants fixated on this cross for 300 ms, it was replaced by the stimulus display. After the stimulus had been displayed for 80 ms, it was replaced by a blank screen with the same gray background (RGB: 128, 128, 128). We checked participants' initial fixation location with respect to the fixation cross to ensure that it was in the region of the fixation cross. The initial fixation location was landed on the site where the fixation cross was. Participants identified whether the stimulus was a word or a nonword by pressing one of two keys as accurately and as quickly as possible. The next trial began immediately following the response. Calibration validation was conducted at the beginning of each trial. The eye tracker was checked and recalibrated if necessary prior to the presentation of each stimulus. Participants were given frequent short breaks between trials to prevent fatigue, and calibration was redone after short breaks between trials. The experiment lasted approximately an hour and a half.

2.2. Results and discussion

Data from trials with incorrect responses (6.3% of the word trials and 9.7% of the nonword trials) or trials with RTs that were three standard deviations above or below the participant's mean RT (2.5% of the word trials and 5.2% of the nonword trials) were excluded in all analyses except accuracy analyses. For each word or nonword condition, and for each length of the stimuli, a repeated-measure analysis of variance (ANOVA) was performed with initial viewing position as the within-participant factor.

2.2.1. Accuracy

The mean accuracy of responses was 94% ($SD = 2.5\%$). Table 1 shows mean accuracy as a function of stimulus lengths and initial viewing positions. The initial viewing position did not affect accuracy for 2-character words, $F < 1.0$, but affected accuracy for 3-character words [$F(2,22) = 11.69$, $MSE = .002$, $p < .01$, $\eta_p^2 = .52$] and 4-character words [$F(3,33) = 19.12$, $MSE = .001$, $p < .001$, $\eta_p^2 = .64$]. For 3-character words, only the linear trend was significant, $F(1,11) = 18.71$, $MSE = .002$, $p < .01$, $\eta_p^2 = .63$. For 4-character words, both the linear and quadratic trends were reliable, $F(1,11) = 18.02$, $MSE = .003$, $p < .001$, $\eta_p^2 = .62$, and $F(1,11) = 32.93$, $MSE = .001$, $p < .001$, $\eta_p^2 = .75$, respectively. However, the cubic trend was not reliable, $F < 1.0$. Moreover, the initial viewing position had a hint of an effect to affect accuracy for 4-character nonwords [$F(3,33) = 2.85$, $MSE = .002$, $p = .05$, $\eta_p^2 = .21$], indicating that in this particular case, the curve showed an inverted U-shape trend. However, the initial viewing position did not affect accuracy for 2- and 3-character nonwords, $F_S < 2.0$. Meanwhile, the results of all pairwise comparisons between the different initial viewing positions for word stimuli in Experiment 1 are provided in Appendix A.

Table 1
Mean accuracy for the lexical decision task of all stimuli lengths on the imposed initial viewing positions in Experiments 1 and 2.

Stimuli length	Character 1	Character 2	Character 3	Character 4
Experiment 1				
Word				
2-Character	.96 (.01)	.96 (.01)		
3-Character	.96 (.01)	.93 (.01)	.88 (.02)	
4-Character	.96 (.01)	.98 (.01)	.95 (.01)	.87 (.02)
Nonword				
2-Character	.84 (.03)	.86 (.02)		
3-Character	.94 (.02)	.95 (.01)	.93 (.02)	
4-Character	.88 (.04)	.92 (.03)	.92 (.04)	.88 (.05)
Experiment 2				
Word				
2-Character	.97 (.01)	.98 (.01)		
3-Character	.93 (.01)	.94 (.01)	.90 (.02)	
4-Character	.98 (.01)	.96 (.01)	.97 (.01)	.96 (.01)
Nonword				
2-Character	.90 (.02)	.93 (.02)		
3-Character	.97 (.01)	.97 (.02)	.97 (.01)	
4-Character	.95 (.01)	.95 (.02)	.97 (.01)	.97 (.01)

Notes: Standard errors appear in parentheses.

In contrast to Brysbaert, Vitu, and Schroyens's (1996) previous study in alphabetic languages, the accuracy in this study was high and it was not affected as much by initial viewing position. This result may have been due to the presentation of the stimuli being not followed by a visual mask so that participants could continue to process stimuli even when they disappeared from the display.

2.2.2. Reaction time

Fig. 1 presents the mean RTs for 2-, 3-, and 4-character stimulus lengths as a function of the initial viewing position. For 2-character words, RT was significantly shorter when the initial viewing position was on the first character than when it was on the second character, $F(1,11) = 20.68$, $MSE = 312.73$, $p < .001$, $\eta_p^2 = .65$. RTs for 3- and 4-character words exhibited a U-shaped curve as a function of the initial viewing position, and RT was shortest when the initial viewing position was on the second character. These observations were confirmed by main effects found for initial viewing position on RT for 3-character words [$F(2,22) = 18.81$, $MSE = 306.50$,

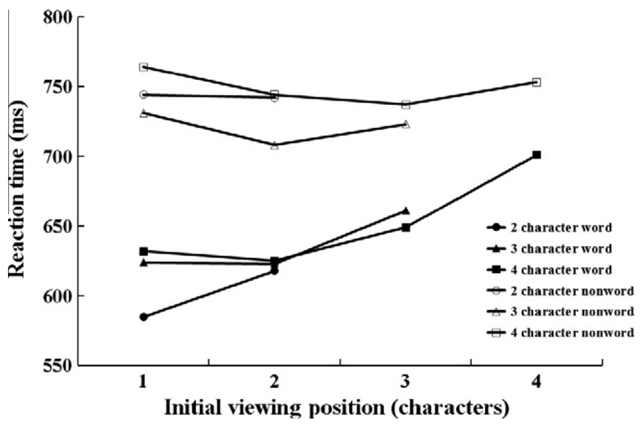

Fig. 1. Lexical decision times for all stimulus lengths as a function of the initial viewing position in Experiment 1.

$p < .001$, $\eta_p^2 = .63$] and 4-character words [$F(3,33) = 25.86$, $MSE = 541.82$, $p < .001$, $\eta_p^2 = .70$]. Both the linear and quadratic trends were reliable for 3-character words [$F(1,11) = 26.12$, $MSE = 328.29$, $p < .001$, $\eta_p^2 = .70$, and $F(1,11) = 10.39$, $MSE = 284.71$, $p < .01$, $\eta_p^2 = .49$] and 4-character words [$F(1,11) = 42.36$, $MSE = 743.99$, $p < .001$, $\eta_p^2 = .79$, and $F(1,11) = 20.77$, $MSE = 506.47$, $p < .01$, $\eta_p^2 = .65$]. The response time increased at a rate of approximately 33 ms per character as the initial fixation deviated from the minimum of the curve.

For nonwords, the initial viewing position has little effect on 2-character nonwords ($F < 1.0$). RTs exhibited a U-shaped curve as a function of the initial viewing position with a minimum at the second character for 3-character nonwords and the third character for 4-character nonwords. These observations were confirmed by main effects found for the initial viewing position on 3- and 4-character nonwords, $F(2,22) = 7.11$, $MSE = 238.88$, $p < .01$, $\eta_p^2 = .39$, and $F(3,33) = 3.38$, $MSE = 461.90$, $p < .05$, $\eta_p^2 = .24$, respectively. The quadratic trend was reliable for both 3-character nonwords [$F(1,11) = 30.30$, $MSE = 99.25$, $p < .001$, $\eta_p^2 = .73$] and 4-character nonwords [$F(1,11) = 7.44$, $MSE = 486.97$, $p < .05$, $\eta_p^2 = .40$]. None of the other effects in trend analyses were reliable, $Fs < 2.0$. The response time increased at a rate of approximately 16 ms per character as the initial fixation deviated from the minimum of the curve.

It is worth noting that stimuli type (word or nonword) was not submitted to the ANOVAs in the above analyses because the character properties for these two kinds of stimuli were not matched. Directly comparing the effects of these two stimuli type might have brought too much noise. Hence, we performed ANOVAs separately above for word and nonword stimuli. To give some sense on whether viewing position effects were different for word and nonwords, we conducted a two-factor ANOVA (stimulus type and initial landing position) on RTs for each stimulus length. The results revealed significant interaction for 2-, 3-, and 4-character stimuli (all $ps < .01$). We found that the effects of initial viewing position on RTs for nonwords were relatively smaller than for words, suggesting that word processing may influence OVP effects. Since this study was not designed to explore this question, we did not explore these differences further.

In summary, the present experiment revealed that the initial viewing position affected the processing time of Chinese words and nonwords presented in isolation. The lexical decision time was shorter when the initial viewing position fell on the first character rather than the second character for 2-character words, but not for 2-character nonwords. For 3- and 4-character words and nonwords, RTs as a function of initial viewing position appeared as a U-shaped curve with a minimum towards the second or third character.

3. Experiment 2

In Experiment 1, the stimuli were presented briefly so that Chinese readers did not have a chance to move their eyes. As stated in the introduction, some eye movement measures are important for us to understand the effect of initial viewing position on word processing. In Experiment 2, the stimuli remained onscreen until participants responded so that eye movement measures could be recorded. As in Experiment 1, participants were instructed to perform a lexical decision task as accurately and as quickly as possible.

3.1. Method

3.1.1. Participants

Twelve native Chinese speakers (7 females) were recruited from the same participant pool as that in Experiment 1 and were paid to take part in the experiment. They ranged in age from 20 to 27 years old ($M = 23.1$, $SD = 2.0$). None of them had participated in Experiment 1.

3.1.2. Materials

The materials were identical to those used in Experiment 1.

3.1.3. Apparatus

The apparatus used in Experiment 1 was employed with the following modifications. Each stimulus was displayed on a single line in Song 26-point font. The size of each Chinese character was 35×35 pixels. Participants were seated at a viewing distance of 58 cm from the computer monitor. At this viewing distance, each character subtended a visual angle of approximately 1.3°.

3.1.4. Procedure

The procedure was identical to that of Experiment 1 with the following modifications. At the beginning of each trial, a white square (subtending approximately $0.9° \times 0.9°$) was displayed in the center of the screen. Once the participant fixated on the white square, two vertically aligned line segments separated by a gap that was the height of one character were displayed in the center of the screen. Participants were instructed to fixate on the space between the lines. After 500 ms, the lines were replaced by the test stimulus display (see Fig. 2). Although the test stimulus appeared at different positions relative to the previously displayed space between the vertical lines, participants were always asked to fixate on this space when the stimulus appeared. The stimulus remained visible until the participant responded by pressing one of two keys that indicated whether the stimulus was a word or a nonword. Participants were instructed to respond as accurately and as quickly as possible. The next trial began immediately after the response.

3.2. Results and discussion

We found that the participants' eyes following the 500-ms presentation of the fixation bars were at the expected location in 86% of trials. The trials in which the eyes had shifted to another letter location were not excluded from analyses, because the analyses conducted after the exclusion of these trials provided findings similar to the results reported below. Data from trials with incorrect responses (approximately 4.0% of the word trials and 4.1% of the nonword trials) or trials with RTs that were three standard deviations above or below the participant's mean RT (2.5% of the word trials and 3.5% of the nonword trials) were excluded in all analyses except accuracy analyses.

We examined accuracy and RTs as well as eye movement measures for the word and nonword stimuli. To determine the extent to which viewing position affected eye behavior, we analyzed the following eye movement measures: (a) *refixation probability* (the probability that the stimulus was fixated more than once), (b) *first fixation duration* (the duration of the first fixation on the stimulus, regardless of the number of fixations), (c) *single fixation duration* (the duration of the first fixation on the stimulus if the stimulus received only one fixation), and (d) *first and second fixation durations in two-fixation cases* (the duration of the first and the second fixation on the stimulus if the stimulus received two fixations). Note that fixation durations included time on the stimulus and they did not include time spent fixating on the fixation bars.

3.2.1. Global measures

Accuracy. The mean accuracy of responses was 95% ($SD = 2.6\%$). For 4-character words, the initial viewing position affected accuracy, $F(3,33) = 4.90$, $MSE = .00$, $p < .01$, $\eta_p^2 = .31$, and accuracy was higher when the initial fixation fell on the first character than when it fell on any other character (see Table 1). The initial viewing position did not affect accuracy for nonwords of 4 characters as

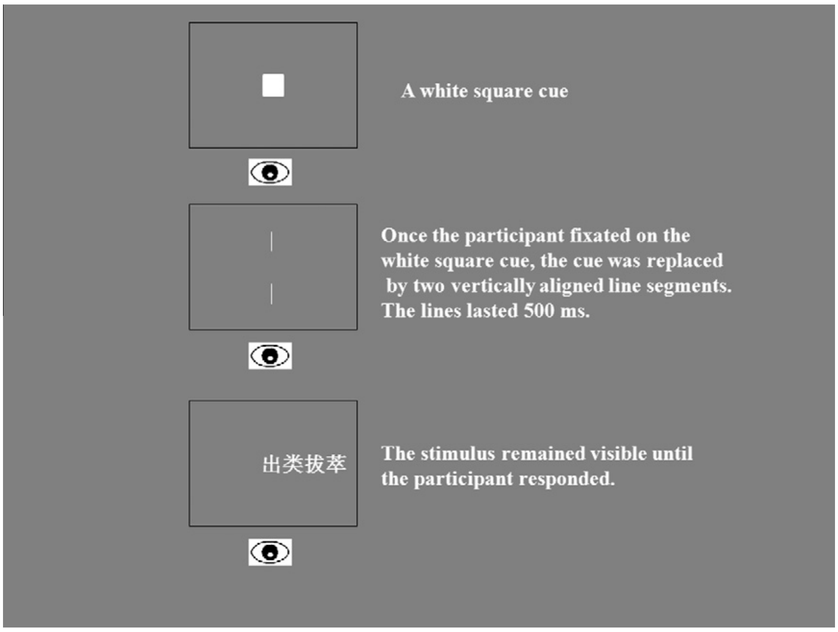

Fig. 2. An example of the paradigm used in Experiment 2 to investigate the OVP (O'Regan & Jacobs, 1992) for the Chinese 4-character word 出类拔萃 ("outstanding"). The word was presented so that on different trials the initial fixation would fall on different character positions. It should be noted that the two vertically aligned line segments and the stimulus were not displayed simultaneously. Participants were first instructed to fixate successfully on the white square, and second on the space between the two line segments for 500 ms. Then the lines disappeared and the test stimulus was displayed. The stimulus remained visible until the participant responded as to whether it was a word or a nonword.

well as words and nonwords of the other tested lengths ($Fs < 2.0$). Because accuracy was high and the differences between the initial viewing position conditions were not large, this finding will not be discussed further.

Reaction time. For words, the initial viewing position affected RTs for all of the word lengths (see Fig. 3). These observations were confirmed by main effects of initial viewing position for 2-character words, $F(1,11) = 27.17$, $MSE = 1252.70$, $p < .001$, $\eta_p^2 = .71$; 3-characters words, $F(2,22) = 18.38$, $MSE = 1810.50$, $p < .001$, $\eta_p^2 = .63$; and 4-character words, $F(3,33) = 36.80$, $MSE = 1464.03$, $p < .001$, $\eta_p^2 = .77$. RTs for 2-character words were shorter when the initial fixation fell on the first character than when it fell on the second character. RTs for 3- and 4-character words exhibited a U-shaped curve as a function of the initial viewing position with a minimum towards the second character. A trend analysis confirmed that these effects were reliable. For 3-character words, both linear and quadratic trends were significant, $F(1,11) = 25.94$, $MSE = 1651.33$, $p < .001$, $\eta_p^2 = .70$, and $F(1,11) = 12.04$, $MSE = 1969.67$, $p < .01$, $\eta_p^2 = .52$, respectively. For 4-character words, the linear, quadratic, and cubic trends were significant, $F(1,11) = 55.44$, $MSE = 1773.98$, $p < .001$, $\eta_p^2 = .83$; $F(1,11) = 25.91$, $MSE = 1655.32$, $p < .001$, $\eta_p^2 = .70$; and $F(1,11) = 21.18$, $MSE = 962.79$, $p < .001$, $\eta_p^2 = .66$, respectively. These results suggest that the initial viewing position affects RTs for words presented in isolation. Meanwhile, the results of all pairwise comparisons between the different initial viewing positions for word stimuli in Experiment 2 are provided in Appendix B.

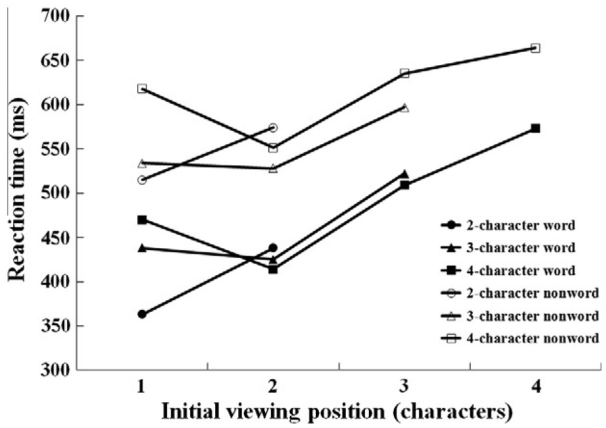

Fig. 3. Lexical decision times for all stimulus lengths as a function of the initial viewing position in Experiment 2.

For nonword stimuli, the initial viewing position affected RTs similarly (see Fig. 3). These effects were significant for 2-character nonwords, $F(1,11) = 14.05$, $MSE = 1485.13$, $p < .01$, $\eta_p^2 = .56$; 3-character nonwords, $F(2,22) = 12.46$, $MSE = 1440.27$, $p < .001$, $\eta_p^2 = .53$; and 4-character nonwords, $F(3,33) = 15.43$, $MSE = 1773.53$, $p < .001$, $\eta_p^2 = .58$. RTs for 2-character nonwords were shorter when the initial fixation fell on the first character. RTs for 3- and 4-character nonwords exhibited a U-shaped curve with a minimum towards the second character. A trend analysis confirmed that these effects were reliable. For 3-character nonwords, both linear and quadratic trends were significant, $F(1,11) = 23.27$, $MSE = 1044.17$, $p < .01$, $\eta_p^2 = .68$, and $F(1,11) = 6.31$, $MSE = 1836.37$, $p < .05$, $\eta_p^2 = .37$, respectively. For 4-character nonwords, the linear, positive quadratic, and cubic trends were significant, $F(1,11) = 23.20$, $MSE = 1254.70$, $p < .01$, $\eta_p^2 = .68$; $F(1,11) = 9.48$, $MSE = 2893.37$, $p < .05$, $\eta_p^2 = .46$; and $F(1,11) = 21.79$, $MSE = 1172.53$, $p < .01$, $\eta_p^2 = .67$, respectively. Moreover, the results of all pairwise comparisons between the different initial viewing positions for nonword stimuli in Experiment 2 are provided in Appendix C. Meanwhile, for both word and nonword stimuli, the response time increased at a rate of approximately 72 ms per character as the initial fixation deviated from the minimal response time. These results suggest that initial viewing position affects RTs for nonwords in a similar manner as words.

3.2.2. Eye movements

Refixation probability. As shown in Fig. 4, the initial viewing position affected refixation probability for 2-character words [*F*

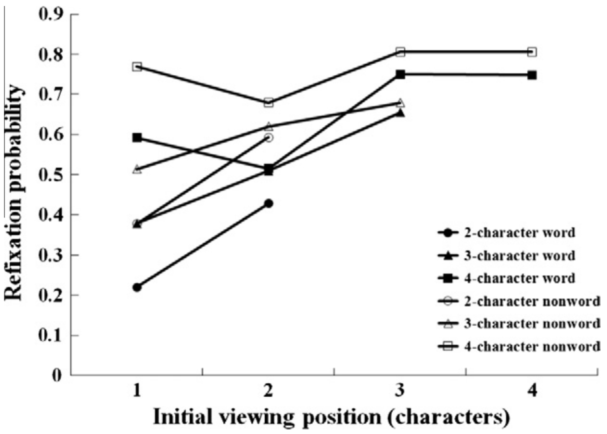

Fig. 4. Refixation probability for all stimulus lengths as a function of the initial viewing position in Experiment 2.

$(1,11) = 12.33$, $MSE = .02$, $p < .01$, $\eta_p^2 = .53$], 3-character words [$F(2,22) = 13.97$, $MSE = .02$, $p < .001$, $\eta_p^2 = .56$], and 4-character words [$F(3,33) = 16.22$, $MSE = .01$, $p < .001$, $\eta_p^2 = .60$]. For both 2- and 3-character words, the refixation probability was lower when the initial fixation fell on the first character than when it fell on any other character. For 3-character words, a polynomial trend analysis showed that the linear trend was reliable [$F(1,11) = 21.79$, $MSE = .02$, $p < .01$, $\eta_p^2 = .66$], though the quadratic trend was not significant, $F < 1.0$. For 4-character words, the linear and cubic trends were reliable [$F(1,11) = 24.36$, $MSE = .01$, $p < .001$, $\eta_p^2 = .69$; and $F(1,11) = 17.17$, $MSE = .01$, $p < .01$, $\eta_p^2 = .61$], although the quadratic trend was not reliable, $F(1,11) = 2.15$, $MSE = .01$, $p = .17$, $\eta_p^2 = .16$.

For nonword stimuli, the initial viewing position also had a strong effect on the refixation probability for 2-character nonwords [$F(1,11) = 19.12$, $MSE = .02$, $p < .01$, $\eta_p^2 = .64$], 3-character nonwords [$F(2,22) = 8.66$, $MSE = .01$, $p < .01$, $\eta_p^2 = .44$], and 4-character nonwords [$F(3,33) = 5.01$, $MSE = .01$, $p < .01$, $\eta_p^2 = .31$]. For 3-character nonwords, the linear trend was reliable [$F(1,11) = 14.19$, $MSE = .01$, $p < .01$, $\eta_p^2 = .56$], though the quadratic trend was not significant, $F < 1.0$. For 4-character nonwords, the quadratic and cubic trends were reliable [$F(1,11) = 5.74$, $MSE = .00$, $p < .05$, $\eta_p^2 = .34$; and $F(1,11) = 5.54$, $MSE = .01$, $p < .05$, $\eta_p^2 = .34$], although the linear trend was marginally significant, $F(1,11) = 3.89$, $MSE = .01$, $p = .07$, $\eta_p^2 = .26$.

In summary, for both 2- and 3-character words and nonwords, the refixation probability was lower when the initial fixation fell on the first character than when it fell on any other character. Perhaps the great information density and importance of perceptual learning in Chinese may cause the refixation OVP to be on the first character for 2- and 3-character words and nonwords. For both 4-character words and nonwords, the refixation probability as a function of initial viewing position exhibited a U-shaped curve with a minimum towards the second character. These results suggest the presence of Refixation-OVP effect, and indicate that the initial viewing position affects refixation probability for nonwords with a similar pattern to that for words presented in isolation.

First fixation duration. The durations of the first fixation were affected by the initial viewing positions for both 3-character words [$F(2,22) = 9.01$, $MSE = 1311.85$, $p < .01$, $\eta_p^2 = .45$] and 4-character words [$F(3,33) = 8.60$, $MSE = 983.79$, $p < .001$, $\eta_p^2 = .44$]. However, no relationship was found for 2-character words, $F(1,11) = 2.19$, $MSE = 1082.52$, $p = .17$, $\eta_p^2 = .17$. As shown in Fig. 5a, for 3- and 4-character words, first fixation duration showed a U-shaped curve as a function of initial viewing position with a minimum towards the second character. For 3-character words, the quadratic trend was reliable, $F(1,11) = 33.55$, $MSE = 746.91$, $p < .001$, $\eta_p^2 = .74$. For

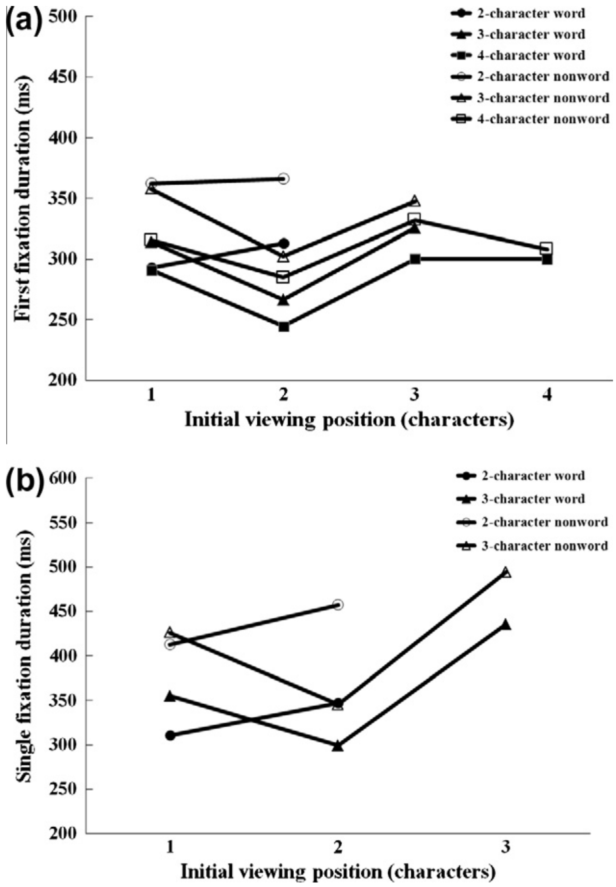

Fig. 5. Fixation durations (a: first fixation duration; b: single fixation duration) for stimulus lengths as a function of the initial viewing position in Experiment 2.

4-character words, the cubic trend was significant, $F(1,11) = 93.38$, $MSE = 159.34$, $p < .001$, $\eta_p^2 = .90$, and the linear [$F(1,11) = 3.82$, $p = .08$] and quadratic [$F(1,11) = 3.73$, $p = .08$] trends were marginally significant.

For nonword stimuli, the results were similar. The initial viewing position affected first fixation duration for both 3-character nonwords [$F(2,22) = 7.01$, $MSE = 1497.12$, $p < .01$, $\eta_p^2 = .39$] and 4-character nonwords [$F(3,33) = 3.62$, $MSE = 1279.48$, $p < .05$, $\eta_p^2 = .25$], but not 2-character nonwords ($p = .82$). As shown in Fig. 5a, RTs showed a U-shape curve as a function of initial viewing position with a minimum towards the second character of 3- and 4-character nonwords. For 3-character nonwords, the quadratic trend was significant [$F(1,11) = 18.71$, $MSE = 1090.03$, $p < .01$, $\eta_p^2 = .63$], and the linear trend was not reliable, $F < 1.0$. For 4-character nonwords, the cubic trend was significant [$F(1,11) = 16.39$, $MSE = 818.51$, $p < .01$, $\eta_p^2 = .60$], and the linear and quadratic trends were not reliable, $Fs < 1.0$.

Single fixation duration. For 4-character stimuli, there were less than 10 items that were fixated only once on average in each initial viewing position. Having few items per condition may result in a pattern of effects that may not be generalizable to a wider range of materials. Thus, we will present results only for 2- and 3-character words and nonwords because there were a reasonable number of data points for single fixations (i.e., there were more than 20 items on average for each initial viewing position). Single fixation duration varied with the initial fixation location for both 2-character words [$F(1,11) = 5.70$, $MSE = 1418.22$, $p < .05$, $\eta_p^2 = .34$] and 3-character words [$F(2,22) = 20.26$, $MSE = 2774.19$, $p < .001$, $\eta_p^2 = .65$]. Fig. 5b shows a U-shape curve of single fixation duration as a function of initial viewing position with a minimum towards the second character of 3-character words. For 3-character words, both linear and quadratic trends were reliable, $F(1,11) = 8.26$, $MSE = 4718.89$, $p < .05$, $\eta_p^2 = .43$; $F(1,11) = 88.57$, $MSE = 829.48$, $p < .001$, $\eta_p^2 = .89$, respectively.

The results of the nonwords showed a similar pattern. For 2-character nonwords, initial viewing position had a marginally significant effect on single fixation duration, $F(1,11) = 3.99$, $MSE = 3009.18$, $p = .07$, $\eta_p^2 = .27$. For 3-character nonwords, initial viewing position had a strong significant effect on single fixation duration, $F(2,22) = 17.32$, $MSE = 3830.11$, $p < .001$, $\eta_p^2 = .61$. Fig. 5b also shows an U-shape curve of single fixation duration as a function of initial viewing position with a minimum towards the second character of 3-character nonwords. For 3-character nonwords, both linear and quadratic trends were reliable, $F(1,11) = 9.43$, $MSE = 2948.48$, $p < .05$, $\eta_p^2 = .46$; $F(1,11) = 22.26$, $MSE = 4711.74$, $p < .01$, $\eta_p^2 = .67$.

In prior studies, single fixation duration was longest when eyes located at the center of a word (Nuthmann, Engbert, & Kliegl, 2007; Vitu et al., 2001; Vitu, Lancelin, & d'Unienville, 2007; Yan et al., 2010). The results of the current study did not replicate the I-OVP effect. The different pattern may be due to the nature of the stimulus display or task, and not necessarily just due to differences in language. The results show that the OVP effect also generalizes to single fixation duration. We will discuss this further later.

First and second fixation duration in two-fixation cases. The fixation-duration trade-off in two-fixation cases shows that the duration of the first fixation is longest and the duration of the second fixation is shortest when the eyes initially fixate near the center of words (McDonald, Carpenter, & Shillcock, 2005; Vitu et al., 2001; Vitu, Lancelin, & d'Unienville, 2007). The present results tested the presence of a fixation-duration trade-off in Chinese. Note that these analyses are all conditional on the location of the first fixation only. The results showed that there was some reliable effect for 3- and 4-character stimuli, but not for 2-character stimuli.

Figs. 6a–c present the fixation durations for trials with two fixations as a function of the initial viewing position for 2-, 3-, and 4-character words. For word stimuli, the analysis included data from trials with only two fixations—31% of the trials for 2-character words, 44% of the trials for 3-character words, and 49% of the trials for 4-character words. Quadratic analyses of the data revealed significant effects on 3- and 4-character words for first fixation durations [$F(1,11) = 9.63$, $MSE = 1903.51$, $p < .05$, $\eta_p^2 = .47$; $F(1,11) = 9.51$, $MSE = 948.48$, $p < .05$, $\eta_p^2 = .46$], but no significant effects for second fixation durations ($Fs < 1.0$). These results indicate that there is no reliable trend for the duration of the second fixation as a function of initial viewing position, but there is a significant quadratic trend for the duration of the first fixation. Thus, for 3- and 4-character words, first fixation duration curves show a larger effect of initial viewing position than second fixation duration curves do. The initial viewing position only influenced the duration of the first fixation and in a direction opposite to what is classically found, and hence opposite to the I-OVP effect. Additionally, the results found for word stimuli did not replicate the fixation-duration trade-off for alphabetic languages (Hyönä & Bertram, 2011; McDonald, Carpenter, & Shillcock, 2005; O'Regan & Lévy-Schoen, 1987; Vitu et al., 2001).

Figs. 7a–c present the duration of first and second fixations for trials with two fixations as a function of the initial viewing position for 2-, 3-, and 4-character nonwords. For nonword stimuli, the data of two-fixation cases subsumed 40% of the trials for 2-character nonwords, 47% of the trials for 3-character nonwords, and 44% of the trials for 4-character nonwords. A quadratic analysis of data revealed significant effects for first fixation duration on 3-character nonwords [$F(1,10) = 19.92$, $MSE = 837.29$, $p < .01$, $\eta_p^2 = .67$], but not on 4-character nonwords, $F < 1.0$. Interestingly, unlike what was found for word stimuli, quadratic analysis revealed a significant effect on second fixation duration for 3-character nonwords [$F(1,10) = 6.97$, $MSE = 969.61$, $p < .05$, $\eta_p^2 = .41$] and a marginally significant effect for 4-character nonwords, $F(1,10) = 3.51$, $MSE = 733.95$, $p = .09$, $\eta_p^2 = .24$. As shown in Fig. 7b, in two-fixation cases, the duration of the first fixation was shortest for initial fixations that occurred at the second character, and the duration of the second fixation exhibited the opposite tendency, with the longest

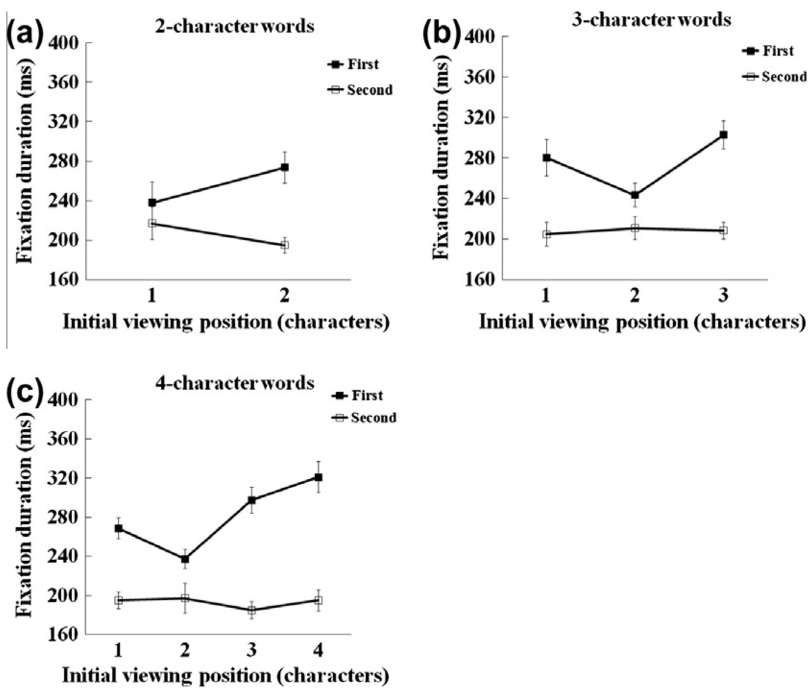

Fig. 6. The mean duration of first and second fixations for two-fixation cases as a function of the initial viewing position for: (a) 2-character words, (b) 3-character words, and (c) 4-character words in Experiment 2. The error bars represent standard errors.

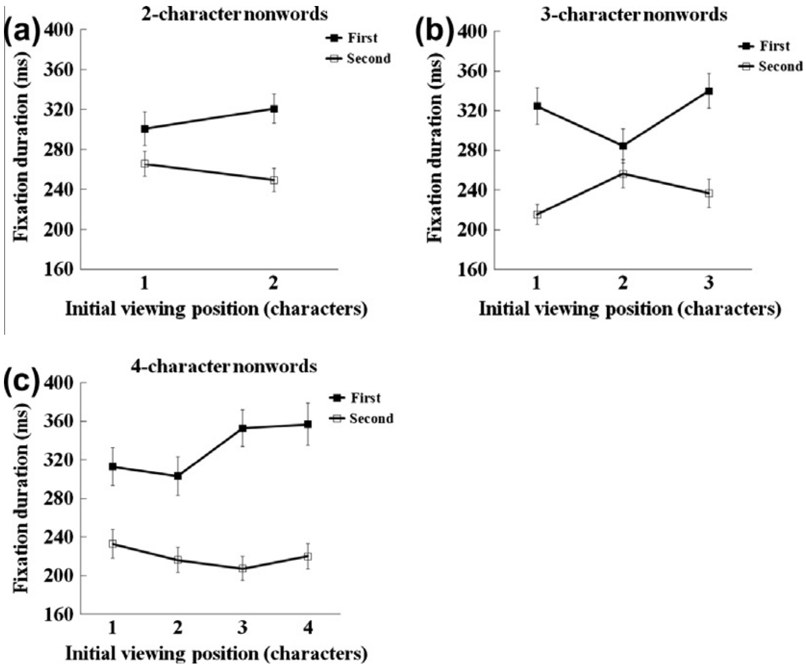

Fig. 7. The mean duration of first and second fixations for two-fixation cases as a function of the initial viewing position for: (a) 2-character nonwords, (b) 3-character nonwords, and (c) 4-character nonwords in Experiment 2. The error bars represent standard errors.

durations for initial fixations at the second character. Thus, nonword data showed a fixation-duration trade-off, but the pattern was exactly opposite to that found in prior studies as there was no I-OVP effect for the duration of first fixations (Nuthmann, Engbert, & Kliegl, 2007; Vitu et al., 2001; Vitu, Lancelin, & d'Unienville, 2007; Yan et al., 2010).

Similar to Experiment 1, we conducted a two-factor ANOVA (stimulus type and initial landing position) on RTs and eye behavior reported above for each stimulus length. For 3- and 4-character stimuli, the results revealed significant interaction for RTs and refixation probability (all $ps < .05$). We also found that the effect of initial viewing position on RTs for nonwords were relatively smaller than for words, suggesting that word properties may influence OVP effects. Nevertheless, for other measures, the interaction was not significant ($ps > .10$).

4. General discussion

In two experiments, we explored how initial viewing position affects word processing efficiency. Overall, the results were consistent with findings for alphabetic languages except for the duration of first fixation, which was minimal and not maximal at the center of words (Brysbaert & Nazir, 2005; Deutsch & Rayner, 1999; Farid & Grainger, 1996; Hyönä & Bertram, 2011; O'Regan & Jacobs, 1992; O'Regan et al., 1984; Van der Haegen, Drieghe, & Brysbaert, 2010; Vitu, O'Regan, & Mittau, 1990). The OVP in the processing of isolated Chinese words tends to be slightly to the left of the center of the word, where processing time is minimal. For 2-character words and nonwords, RTs were shorter when the initial viewing position was on the first character than when it was on the second character. For 3- and 4-character words and nonwords, we observed a U-shaped curve of RTs as a function of initial viewing position with a minimum towards the second character. As the fixation location deviated from the OVP, for word stimuli, there was a time cost which increased at a rate of 30–70 ms per character, which was slightly greater than the processing time cost reported for French (O'Regan et al., 1984).

Many factors may contribute to the word-identification OVP effect. Brysbaert and Nazir (2005) argued that OVP effects may be caused by four factors: (1) decreases of visual acuity as distance from the fixation location increases, (2) word beginnings providing more information than word endings for word identification, (3) perceptual learning based on reading habits (e.g., letters are recognized in the right visual field more often for languages that are read from left to right), and (4) most letters falling on the right visual field when the left side of a word is fixated allowing the information to be directly processed by the language-dominant left hemisphere. Thus, findings that the OVP in word recognition of most alphabetic languages is biased to the left of the word center may be due to the structure of the word stimuli, perceptual learning, or hemispheric asymmetry in word processing. Recently, Hsiao and Liu (2012) found similar OVP effects for the area left of the center of the face in facial recognition, which suggests that perceptual experience exerts greater influence than hemisphere asymmetry in visual processing. Thus, we will discuss the extent to which the first three factors might contribute to OVP effects in Chinese below.

First, the visual acuity limitation may explain the finding that as the distance between fixation location and OVP location increased, the participants' performance to recognize the stimulus was reduced. Previous investigations have suggested that the decrease in visual acuity with retinal eccentricity contributes to the OVP effects for word recognition, because visual acuity decreases with a character's distance from the location of fixation, resulting in a loss of visual information (Brysbaert & Nazir, 2005; Nazir, 1991; Rayner, 2009; Vitu, Lancelin, & d'Unienville, 2007). When participants were required to fixate on the beginning or end of the stimulus, visual-acuity limitations reduced participants' ability to recognize the words. Thus, in the present study, response times were longer for 2-, 3- and 4-character words and nonwords when the initial fixation fell on the final character, or to a smaller extent the first character of 3- and 4-character words, than when it fell on other characters.

However, participants did not find it difficult to recognize a word or nonword when the fixation occurred at the beginning of the stimulus. In both experiments, response times were shorter when the initial fixation fell on the first character than when it fell on the final character. These results suggest that word beginning may play an important role in word-identification OVP effect. Prior studies have demonstrated that the initial letter of a word provides a great deal of information, and knowledge of the initial letter is more effective than knowledge of the final letter for word identification (Broerse & Zwaan, 1966; Brysbaert & Nazir, 2005; Eriksen & Eriksen, 1974; Li & Pollatsek, 2011; White et al., 2008; Yan et al., 2006). However, the importance of first character may not account for the OVP effects found for nonword stimuli, because the individual Chinese characters in nonwords were randomly selected regardless of the first or final characters.

Consequently, perceptual learning based on reading habits (Brysbaert & Nazir, 2005; Deutsch & Rayner, 1999; Farid & Grainger, 1996; Nazir et al., 2004; Wong & Hsiao, 2012) might account for the word-identification OVP effect. Because Chinese is read from left to right, words are repeatedly recognized in the same location in the visual field. Chinese readers form the reading habits to process information from left to right. As a result, when the initial fixation occurs at the location that readers most often fixate while reading, word recognition is more effective (Brysbaert & Nazir, 2005; Ducrot & Pynte, 2002). Reading habits can also account for the OVP effect in nonword stimuli, because the information in the right visual field may be more effectively processed than that in the left visual field so that the OVP might be slightly to the left of the word center. Several prior studies have explored the effect of reading direction and morphological structure on OVP effects (Deutsch & Rayner, 1999; Farid & Grainger, 1996; Nazir et al., 2004). These studies raise the question of how these factors may influence the OVP effects in Chinese; this will need further investigation. In any case, reading habits and/or direction might play critical roles in word-identification OVP effects during the processing of isolated Chinese words and nonwords as indexed by lexical decision time and accuracy.

Furthermore, we also observed some interesting eye-movement related OVP effects. Specially, a Refixation-OVP effect was found for both 4-character words and nonwords, showing that the refixation probability was lower when the eyes initially fixated near the center of a word than towards its beginning or end. The findings were consistent with the results of prior studies (e.g., Nazir, 1991; O'Regan et al., 1984; Vitu, O'Regan, & Mittau, 1990; Vitu et al., 1995; Vitu, Lancelin, & d'Unienville, 2007). For 2- and 3-character words, the refixation probability was lower when the initial viewing position was on the first character than when it was on the other characters. Moreover, the study showed that refixation probability increased as word length increased. Although the effect of word length in the present study could be due to differences in word frequency, complexity, and character features, it is still consistent with the effect of word length reported in previous studies (Joseph et al., 2009; Plummer & Rayner, 2012; Rayner et al., 2011). However, the present study did not observe the fixation-duration I-OVP effect found in alphabetic languages (Nuthmann, Engbert, & Kliegl, 2005; Vitu et al., 2001; Vitu, Lancelin, & d'Unienville, 2007). The study also did not reveal a fixation-duration trade-off for 2-fixation cases in words and that the one observed for nonwords was in the opposite direction to the one typically reported.

The effect of initial viewing position on eye movement measures was similar for word and nonword stimuli. The results were consistent with prior studies using letter strings in a mindless-reading task (Nazir, 1991; Nuthmann, Engbert, & Kliegl, 2007; Vitu et al., 1995). The similar OVP effects for words and nonwords suggest that predetermined oculomotor strategies might be an important determinant of the viewing position effect, and may play a greater role than ongoing lexical processing (Nazir, 1991; Vitu et al., 1995). Interestingly, several studies found similar OVP effects for facial recognition and music reading, which do not contain any linguistic information to process (Hsiao & Liu, 2012; Wong & Hsiao, 2012). The present finding suggests that OVP effects may be more related to perceptual experience or oculomotor strategies and therefore that ongoing lexical processing may not contribute much. According to the strategy-tactics theory, readers' predetermined oculomotor scanning routines and perceptual experience may determine within-word eye behavior. Thus, the finding of OVP effects in the processing of isolated Chinese words is consistent with the predictions of the strategy-tactics theory.

Although the initial viewing positions affected eye movements similarly for words and nonwords, the effects, on some measures, for nonwords were relatively smaller than for words. For 3- and 4-character stimuli, the results revealed significant interaction between stimulus type and initial viewing position for RTs in both experiments. For 2-character stimuli, the results revealed significant interaction for RTs in Experiment 1. These results suggest that viewing position affects eye behavior differently for word and nonword stimuli, and that word properties also influence OVP effects. Further studies are needed to specifically address this question.

The present study did not show a fixation-duration trade-off in two-fixation cases nor an I-OVP effect for first fixation durations in the case of word stimuli. There was some kind of a fixation-duration trade-off for nonwords, but simply exactly opposite to what is usually found in alphabetic languages (Hyönä & Bertram, 2011; McDonald, Carpenter, & Shillcock, 2005; Nuthmann, Engbert, & Kliegl, 2005; O'Regan & Lévy-Schoen, 1987; Vitu et al., 2001; Vitu, Lancelin, & d'Unienville, 2007). Likewise, in natural Chinese reading, Yan et al. (2010) did not find the fixation-duration trade-off but observed a reliable I-OVP effect for 2-character words: an inverted U-shaped curve of single fixation duration as a function of initial landing position with a maximum towards the first half character zone of the second character.

One possibility for the difference between the present findings and those reported by Yan et al. (2010) on the I-OVP effect in the reading of Chinese sentence could potentially arise from differences between isolated word recognition and natural sentence reading. However, it should be noted that the I-OVP effect in alphabetic languages was reported not only during natural reading (Nuthmann, Engbert, & Kliegl, 2005; Vitu et al., 2001) but also during isolated word recognition (Vitu, Lancelin, & d'Unienville, 2007). Thus, the reading paradigm cannot be the whole explanation. Another possibility for the different pattern may be due to the use of different word stimuli or stimuli display in Yan et al.'s (2010) study and the present study. Note however that the present study was not designed to explore this question, and further studies are needed to fully understand the discrepancy between the two sets of findings.

Additionally, the absence of an I-OVP effect did not support the anatomical account in SERIF model (McDonald, Carpenter, & Shillcock, 2005). According to the anatomical account, fixation duration would be longer when participants fixate on the second character of 3- and 4-character words as opposed to fixating on one of words' ends because of prolonged competition when the information content is similar between the left and right hemispheres. However, the results showed that fixation duration was shorter on the second character, and hence did not support the predictions of the anatomical account.

According to Vitu, Lancelin, and d'Unienville's (2007) perceptual-economy account, if Chinese readers have developed the same perceptual-motor strategies relying on extraction of word boundary information as English readers, I-OVP or fixation-duration trade-off may be observed. However, these effects were not detected in the processing of isolated Chinese words. Perhaps Chinese readers do not develop similar perceptual-motor strategies due to the lack of inter-word spaces. Noticeably, the presence of perceptual-motor strategies in Chinese readers should be explored in the future. Meanwhile, the present study cannot rule out the mislocation hypothesis, because there were no mislocated fixations arising from oculomotor errors as the eye's initial fixation location in words was determined experimentally. The I-OVP effect and its mechanisms in Chinese still need further investigation.

In summary, the present study found that OVP effects occurred during the processing of isolated Chinese words. In Chinese, the OVP might be slightly to the left of the center of the word. The OVP tended to fall on the initial character for 2-character words. For 3- and 4-character words, the OVP effect appears as a U-shaped curve with a minimum towards the second character. The present study may be the first systematic study to explore the OVP effects in the processing of isolated Chinese words, and may help elucidate visual word recognition in Chinese.

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Appendix A

See Table A1.

Appendix B

See Table B1.

Appendix C

See Table C1.

Table A1
Accuracy and reaction time measures: ANOVA results of the pairwise comparisons between different imposed initial viewing positions for word and nonword stimuli in Experiment 1.

	Accuracy_Words			Reaction time_Words			Reaction time_Nonwords		
	F	*MSE*	η_p^2	*F*	*MSE*	η_p^2	*F*	*MSE*	η_p^2
3-Character words									
Char 1 vs Char 2	4.28[+]	.001	.28	.00			16.00	411	.59
Char 1 vs Char 3	18.71	.004	.63	26.12	657	.7	1.03		
Char 2 vs Char 3	8.29	.004	.43	27.74	629	.72	10.68	265	.49
4-Character words									
Char 1 vs Char 2	2.46			.73			5.04	902	.31
Char 1 vs Char 3	1.03			5.50	589	.33	12.80	659	.54
Char 1 vs Char 4	18.38	.006	.63	40.84	1381	.79	1.63		
Char 2 vs Char 3	5.62	.001	.34	7.75	857	.41	.69		
Char 2 vs Char 4	27.60	.005	.72	37.97	1808	.78	.57		
Char 3 vs Char 4	28.24	.003	.72	31.33	1041	.74	3.66[+]	766	.25

Note: The degrees of freedom were (1, 11) for the pairwise comparison. Char = Character.
[*] $p < .05$.
[**] $p < .01$.
[***] $p < .001$.
[+] $.05 < p < .10$.

Table B1
Reaction time and eye movement measures: ANOVA results of the pairwise comparisons between different imposed initial viewing positions for word stimuli in Experiment 2.

	Reaction time			Refixation probability			First fixation duration			Gaze duration		
	F	*MSE*	η_p^2	*F*	*MSE*	η_p^2	*F*	*MSE*	η_p^2	*F*	*MSE*	η_p^2
3-Char words												
Char 1 vs Char 2	.35			6.35	.02	.37	10.34	2620	.49	1.47		
Char 1 vs Char 3	25.94	3303	.70	21.79	.04	.66	.44			20.34	4562	.65
Char 2 vs Char 3	45.34	2475	.81	10.56	.02	.49	28.17	1497	.72	65.62	2405	.86
4-Char words												
Char 1 vs Char 2	8.64	2192	.44	2.71			16.50	1569	.60	9.97	2156	.48
Char 1 vs Char 3	6.72	2806	.38	25.43	.01	.70	.38			6.03	3591	.35
Char 1 vs Char 4	30.97	4112	.74	10.97	.03	.50	.49			22.95	5252	.68
Char 2 vs Char 3	80.91	1361	.88	35.52	.02	.76	77.39	477	.88	104.28	1205	.91
Char 2 vs Char 4	110.21	2760	.91	27.28	.02	.71	13.89	2647	.56	109.12	2818	.91
Char 3 vs Char 4	22.48	2145	.67	.00			.00			28.28	1415	.72

Note: The degrees of freedom were (1, 11) for the pairwise comparison. Char = Character.
[*] $p < .05$.
[**] $p < .01$.
[***] $p < .001$.

Table C1
Reaction time and eye movement measures: ANOVA results of the pairwise comparisons between different imposed initial viewing positions for nonword stimuli in Experiment 2.

	Reaction time			Refixation probability			First fixation duration			Gaze duration		
	F	*MSE*	η_p^2	*F*	*MSE*	η_p^2	*F*	*MSE*	η_p^2	*F*	*MSE*	η_p^2
3-Char nonwords												
Char 1 vs Char 2	.11			8.18	.02	.43	9.18	4024	.46	1.49		
Char 1 vs Char 3	23.27	2088	.68	14.19	.02	.56	.31			21.74	1971	.66
Char 2 vs Char 3	27.29	2147	.71	2.25			21.60	1151	.66	60.76	1346	.85
4-Char nonwords												
Char 1 vs Char 2	9.43	5721	.46	3.36+	.03	.23	12.41	922	.53	7.68	5457	.41
Char 1 vs Char 3	.61			3.05			.88			1.23		
Char 1 vs Char 4	11.29	2195	.51	.73			.46			13.82	2047	.56
Char 2 vs Char 3	31.79	2659	.74	9.32	.02	.46	16.73	1603	.60	32.30	2531	.75
Char 2 vs Char 4	49.88	3045	.82	11.50	.02	.51	2.71			44.34	3136	.80
Char 3 vs Char 4	4.79	2046	.30	.00			1.33			4.21+	1797	.28

Note: The degrees of freedom were (1, 11) for the pairwise comparison. Char = Character.
* $p < .05$.
** $p < .01$.
*** $p < .001$.
+ $.05 < p < .10$.

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